US-0101-5A

ADAPTIVE ARRAY ANTENNA-BASED CDMA RECEIVER THAT CAN FIND THE WEIGHT VECTORS WITH A REDUCED AMOUNT OF CALCULATIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention generally relates to an adaptive array antenna-based radio receiver of a base station used in a CDMA communications system and, more specifically, to an antenna signal processing system, provided in such a radio receiver, for receiving reception signals from a plurality (M) of antennas and detecting and extracting a channel signal from each of a plurality (N) of users or mobile stations.

2. Description of the Prior Art

Generally speaking, a user of a cellular radio or mobile telephone system communicates through a base station the service area of which includes the location of the user. Such a base station acquires a channel for communication with each of the terminals or users within the service area of the base station so as to set the environments to enable simultaneous multiple communications. Recently, CDMA (code-division multiple access) is attracting great attention as one of such multiplexing techniques.

In a DCMA system, multiplexing is achieved by using, for a plurality of users, respective different spreading codes. For example, a transmission signal for each of the N users is expressed as:

$$x_i(t) = \alpha \cdot c_i(t) \cdot d_i(t) \cdot \exp(j2\pi ft), \qquad (1)$$

where α is a propagation coefficient, $c_i(t)$ is a spreading code allocated to an i-th user, $c_i(t)$ is a datum to be transmitted, f is the frequency of the carrier wave, and i = 1, 2, 3,..., N, where N is the number of users the receiver can provide with radio telephone service. However, we usually omit the subscripts, simply denoting, e.g., x(t), c(t) and d(t) except when the discussion involves any

relationship between different communications or channels. The data or the value of the transmission signal is updated every unit period Td of time. Similarly, the spreading code c(t) is updated every period Tc of time. The ratio between the data update period Td and the spreading code update period Tc is referred to as spreading gain G. The spreading gain G=Td/Tc is usually so set as to be an integer equal to or more than one.

In a CDMA system, the transmission data signals $d_1(t)$, $d_2(t)$, ..., $d_N(t)$ of N users served by a certain base station are multiplied by respective spreading codes $c_1(t)$, $c_2(t)$, ..., $c_N(t)$. For each $c_i(t)$ of the spreading codes (or possible channels), a CDMA receiver is provided with a spreading code-matched filter MF_i for extracting the data $d_i(t)$ from the received signal. The extracted signal or the signal, in the base band, passed through each matched filter MF_i is given as:

$$y_i(t) = \alpha \cdot G \cdot d_i(t). \tag{2}$$

In this way, using matched filters enable simultaneous reception of signals from a plurality of users. Though the number of users served by a base station is limited by the number of spreading codes and the amount of interference among channels, a rapid increase in the number of subscribers of mobile telephone service requires each base station to accommodate more subscribers. In order to cope with this situation, various receivers each incorporating an adaptive array antenna have been proposed so far.

There are reports concerning CDMA receivers with an adaptive array antenna in the following references:

(1) Tanaka, Higuchi, Sawahashi and Adachi, "Indoor Transmission Test Characteristics of DS-CDMA Adaptive Array Antenna Diversity", IEICE (The Institute of Electronics, Information and Communication Engineers), Radio Communication System Society Technical Report RCS98-53, June

1998, pp. 19-24.

(2) Tanaka, Harada, Sawahashi and Adachi, "Outdoor Transmission Test of Adaptive Antenna Array Diversity Reception in DS-CDMA" IEICE, Radio Communication System Society Technical Report RCS99-10, April 1999, pp. 19-24.

(3) Harada, Tanaka, Ihara, Sawahashi and Adachi, "The Results of Indoor Transmission Test of Adaptive Antenna Array Transmission Diversity in a W-CDMA down link" IEICE, Radio Communication System Society Technical Report RCS99-157, November 1999, pp. 115-121.

(4) Ohgane and Ogawa, "The Adaptive Array and Mobile Communications (II)", IEICE Trans., Vol. 82, No. 1, January 1999, pp. 55-61.

Also, though various adaptive array algorithms have been proposed so far, the SMI (Sample Matrix Inversion) algorithm, the RLS (Recursive Least Squares) algorithm and the LMS (Least Mean Square) algorithm are better used among others as described in reference (4). The SMI and RLS algorithms, which both involve the calculation of correlation matrices of input signals, are fast in convergence but requires a large amount of calculations, while the LMS algorithm is less in the amount of calculations but slow in convergence. In this connection, all of references (1) through (3) use the LMS algorithm.

FIG. 1 is a schematic block diagram showing a structure of a conventional adaptive array antenna portion in a multi-user CDMA receiver. In FIG. 1, the adaptive array antenna portion 1 comprises M radio portions 10-1 through 10-M which each include an antenna (not shown) constituting an antennal array (not shown), and an antenna signal procession system 20. The antenna signal procession system 20 comprises N adaptive array signal processors 100-1 through 100-N provided for available channels CH1 through CHN or the users supported by the CDMA receiver or the base station

including the CDMA receiver (M = 4 in this specific example). In each of the radio portions 10, a reception signal received by the antenna is subjected to a frequency conversion and a synchronous detection to become a complex baseband signal xj (j = 1, 2, ..., M), which has an in-phase component as the real part and a quadrature component as the imaginary part. The complex baseband signals x1 through xM (x4 in this example) output from the radio portions 10 are supplied to each signal processor 100-i.

FIG. 2 is a block diagram showing a structure of each adaptive array signal processor 100-i of FIG. 1. It is assumed that the signal processors 100 use above-mentioned SMI algorithm for example. In FIG. 2, the signal processor 100-i comprises M matched filters MFi 111 which are configured to match a spreading code $\bar{c}i(t)$, an adaptive array weight calculator 112-i, M weight multipliers 113 and a signal combiner 114. The adaptive array signal processors 100-1 through 100-N are identical to each other in structure except that the matched filters MF1 through MFN of signal processors 100-1 through 100-N are so configured as to match respective spreading codes c1(t) through cN(t).

In FIG. 2, i.e., in each signal processor 100-i, the baseband signals x1 through x4 from the radio portions 10 are applied to the matched filters 111 in a one-to-one correspondence and despread into despread signals $y_{i,1}$, $y_{i,2}$, $y_{i,3}$, and $y_{i,1}$, which are supplied to the adaptive array weight calculator 112-i and to respective one of the M weight multipliers 113.

The adaptive array weight calculator 112-i calculates a correlation matrix **Φi** and a response vector **Ui**, and then calculates a weight vector **Wi** expressed as:

$$\mathbf{Wi} = \mathbf{\Phi i}^{-1} \cdot \mathbf{Ui}. \qquad (3)$$

where Φi^{-1} is an inverse matrix of Φi.

The correlation matrix Φi is given by:

$$\Phi_i = E\left\{\begin{bmatrix} y_1 y_1^* & y_1 y_2^* & y_1 y_3^* & y_1 y_4^* \\ y_2 y_1^* & y_2 y_2^* & y_2 y_3^* & y_2 y_4^* \\ y_3 y_1^* & y_3 y_2^* & y_3 y_3^* & y_3 y_4^* \\ y_4 y_1^* & y_4 y_2^* & y_4 y_3^* & y_4 y_4^* \end{bmatrix}\right\} \qquad (4)$$

where A^* is a complex conjugate to A, and E{ **B** } indicates a mean of matrices **B** for a lot of data samples. It is noted that the subscript "i" of each variable $y_{i,j}$ (j=1, 2, 3, 4) has been omitted in the above expression. In expression (4), each element of the matrix indicates a correlation between signals from matched filters 111. The calculation of the correlation matrix Φi, which involves an averaging for data samples, is usually conducted in a time area in which the radio propagation environment is less changeable. The value of the correlation matrix Φi is updated when the radio propagation environment has changed.

The response vector **Ui** is calculated by using reference signals included in the despread signals $y_{i,1}$ through $y_{i,4}$. Specifically, the weight calculator 112-i filters the signals $y_{i,1}$ through $y_{i,4}$ with respective filters each configured to match the reference signals included in the signals $y_{i,1}$ through $y_{i,4}$ to obtain filtered signals $u_{i,1}$ through $u_{i,4}$, which yields the response vector **Ui** as follows:

$$\mathbf{Ui} = \begin{pmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{pmatrix}. \qquad (5)$$

It is noted that the subscript "i" of each variable $u_{i,j}$ (j=1, 2, 3, 4) has been omitted in the above expression. The calculated vector elements $u_{i,1}$ through $u_{i,4}$ is used by the weight multipliers 113 to multiply the despread

signals $y_{i,1}$ through $y_{i,4}$, respectively. The output signals from the weight multipliers 113 are combined by the combiner 114 to yield a channel signal zi associated with an i-th user or mobile station.

However, as seen from the above description, if a CDMA receiver is to support N users, then finding N weights requires N calculations for correlation matrices Φ **1** through Φ **N**, N calculations for inverse matrices $\Phi \mathbf{1}^{-1}$ through $\Phi \mathbf{N}^{-1}$ of correlation matrices, N calculations for response vectors **U1** through **UN** and N syntheses of weight vectors **W1** through **WN**, making a total of 4N calculations. Especially, finding a correlation matrix $\Phi \mathbf{i}$ and finding an inverse matrix $\Phi \mathbf{i}^{-1}$ each requires a large amount of calculations, accordingly needs a large circuit and a plenty of electric power. This is a serious obstacle to introduction of the adaptive array antenna to mobile communications. Further, if the CDMA receiver is a RAKE receiver that uses a plurality of (e.g., K) radio paths and, for this, executes a weight vector calculation for each of the K radio path, then the overall weight vector calculation requires $4N \cdot K$ calculations, which requires a larger circuit and more electric power.

Also, since the propagation path can always vary in mobile communications, a CDMA receiver needs a control of tracking the variation. However, the LMS algorithm is disadvantageously slow in convergence of weight vectors **W1** through **WN**, failing to track variations in the propagation path.

Therefore, it is an object of the invention to provide an antenna signal processing system for use in an adaptive array antenna-based CDMA receiver which system can find the weight vectors with a reduced amount of calculations. The CDMA receiver may be a RAKE receiver.

It is another object of the invention to provide an antenna signal

processing system for use in an adaptive array antenna-based CDMA receiver which system is fast enough in convergence of weight vectors to track the variations in the propagation path.

It is further object of the invention to provide a CDMA receiver provided with an adaptive array antenna and such an antenna signal processing system.

SUMMARY OF THE INVENTION

The above and other objects are achieved by a technique of extracting a channel signal transmitted from each of a first plurality of users or mobile stations from reception signals derived from a second plurality of antennas constituting an antenna array in a CDMA receiver. It is assumed that the reception signals have not yet passed through respective matched filters configured to match a spreading code of each user.

According to an aspect of the invention, at least a common correlation matrix is calculated by using the reception signals. Preferably, the inverse matrix of the common correlation matrix is also calculated. The common correlation matrix or the inverse matrix is used in common to the weight calculations for all the users. An inventive CDMA receiver includes a portion provided for each user, i.e., adaptive array signal processors. Each adaptive array signal processor passes the reception signals through the respective matched filters to obtain respective despread signals; calculates a weight vector by using the common correlation matrix or the inverse matrix thereof; weighs the respective despread signals with the weight vector to obtain weighed despread signals; and combines the weighed despread signals into the channel signal associated with each user.

Since a common correlation matrix and the inverse matrix thereof are calculated only once and used in common to the weight calculations for all the

users, the amount of calculations involved in the weight calculations is much reduced.

Further, calculating the correlation matrix in an upstream path of the matched filters 111 enables the period of correlation matrix calculations to be set to any desired value such as the symbol period, the chip time (or the code period), etc. The shorter the calculation period is, the shorter the time necessary for weight convergence becomes.

Also, if a long code is used as the spreading code, a noise-reduced output signal is obtained.

The invention is also applicable to a RAKE receiver. Similarly, the common correlation matrix and the inverse matrix thereof are calculated only once and used in common to all of the users and to the propagation paths of a transmission signal from each users. The RAKE receiver includes first portions provided for respective users. Each of the first portions passes the reception signals through respective matched filters to obtain respective despread signals. Each of the first portions includes second portions provided for the propagation paths of a transmission signal from the user. Each of the second portions calculates a weight vector adapted to one of the propagation paths by using the common correlation matrix or the inverse matrix thereof; weighs the respective despread signals with the weight vector to obtain weighed despread signals; and combines the weighed despread signals into a channel signal component that has passed through the propagation path. Then, the channel signal components are combined together into the channel signal.

This embodiment enables a further reduction of the calculation amount.

According to a second illustrative embodiment, a conversion matrix is calculated from said reception signals; and the reception signals are converted

by using the conversion matrix to obtain respective converted signals. A portion provide for each user passes the respective converted signals through respective matched filters configured to match a spreading code of each user to obtain respective despread signals; and maximum-ratio combines the respective despread signals into the channel signal associated with each user.

BRIEF DESCRIPTION OF THE DRAWING

Further objects and advantages of the present invention will be apparent from the following description of the preferred embodiments of the invention as illustrated in the accompanying drawing, in which:

FIG. 1 is a block diagram showing a structure of a conventional adaptive array antenna portion in a multi-user CDMA receiver (not shown);

FIG. 2 is a block diagram showing a structure of each adaptive array signal processor 100-i of FIG. 1;

FIG. 3 is a schematic block diagram showing an arrangement of a multi-user CDMA receiver in accordance with a first illustrative embodiment of the invention;

FIG. 4 is a flowchart showing an operation of the correlation matrix calculator 200 of FIG. 3;

FIG. 5 is a schematic block diagram showing an arrangement of the adaptive array signal processor 100a-i of FIG. 3;

FIG. 6 is a flowchart showing an exemplary operation of the adaptive array weight calculator 120-i of FIG. 5;

FIG. 7 is a schematic block diagram showing an arrangement of a RAKE receiving portion 300-i which, when substituted for the adaptive array signal processor 100a-i, enables the antenna signal processing system 30 to realize a RAKE reception;

FIG. 8 is a schematic block diagram showing an arrangement of a

multi-user CDMA receiver in accordance with a second illustrative embodiment of the invention;

FIG. 9 is a flowchart showing an exemplary operation of the matrix calculator 420 of FIG. 8;

FIG. 10 is a schematic block diagram showing an arrangement of the adaptive array signal processor 100c-i of FIG. 8; and

FIG. 11 is a schematic block diagram showing an arrangement of an RLS algorithm-based adaptive array signal processor 500 that can be substituted for the adaptive array signal processor 100a in FIG. 3.

Throughout the drawing, the same elements when shown in more than one figure are designated by the same reference numerals.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiment I

FIG. 3 is a schematic block diagram showing an arrangement of a multi-user CDMA receiver 2 using an adaptive array antenna (not shown) in accordance with a first illustrative embodiment of the invention. In FIG. 3, the adaptive array antenna portion 2 comprises M radio portions 10-1 through 10-M which each include an antenna (not shown) constituting an antennal array (not shown); an antenna signal procession system 30; and M detectors 35-1 through 35-M. M is the number of antennas (not shown) of the not-shown antenna array. It is noted that the antenna signal processing system 30 of FIG. 3 is identical to that 20 of FIG. 1 except that, in FIG. 3, each adaptive array signal processor 100-i has been replaced with a corresponding adaptive array signal processor 100a-i, and a correlation matrix calculator 200 shared by the M adaptive array signal processors 100a has been added. The radio portion 10

output signals x1 through xM (M = 4 in this specific example) are coupled with the input terminals of the correlation matrix calculator 200, which has its output supplied to each of the adaptive array signal processors 100a-1 through 100a-N. The output signal zi of each adaptive array signal processor 100-i is supplied to a corresponding detector 35-i, which detects transmitted data from i-th user.

FIG. 4 is a flowchart showing an operation of the correlation matrix calculator 200. In

According to the principles of the invention, a correlation matrix Φ common to all of the users or mobile stations is calculated from the output signals x1 through x4 of the radio portions 10-1 through 10-M. Specifically, the correlation matrix calculator 200 calculates a common correlation matrix Φ from the signals x1 through x4 to be input to the respective adaptive array signal processors 100a-1 through 100a-N as shown in step 202. In this case, the common correlation Φ matrix is expressed as follows:

$$\Phi = E\left\{\begin{bmatrix} X_1X_1^* & X_1X_2^* & X_1X_3^* & X_1X_4^* \\ X_2X_1^* & X_2X_2^* & X_2X_3^* & X_2X_4^* \\ X_3X_1^* & X_3X_2^* & X_3X_3^* & X_3X_4^* \\ X_4X_1^* & X_4X_2^* & X_4X_3^* & X_4X_4^* \end{bmatrix}\right\}, \tag{6}$$

where A^* is a complex conjugate to A, and E{ **B** } indicates a mean of matrices **B** for a lot of data samples. Thus, each element of the common correlation matrix Φ is an average, taken for a certain period of time, of the correlation between a pair (including duplication of a single signal) from the signals x1 through x4 from the antennas (not shown) or the radio portions 10-1 through 10-4.

Usually, the signals received by the antenna are subjected to sampling before being converted into respective baseband signals. In the CDMA system, the baseband reception signals have been sampled at an interval equal to or shorter than the update interval Tc of the spreading code. In this embodiment,

the averaging of the correlation values may be carried out for the radio portion 10 output signals x1 through x4 for every period Tc in the calculation of the common correlation matrix Φ. The averaging may be done at a longer interval; e.g., every symbol period Td of the transmission data. Also, the averaging of the correlation values may be done at irregular intervals. For the sake of the simplicity, it is assumed that the radio portion 10 output signals are detected every symbol period Td for the correlation matrix calculation.

Following the correlation matrix calculation, the correlation matrix calculator 200 calculates the inverse matrix Φ^{-1} of the common correlation matrix Φ in step 204. The value of the calculated inverse matrix Φ^{-1} is supplied to each of the adaptive array signal processors 100a-1 through 100a-N.

FIG. 5 a schematic block diagram showing an arrangement of the adaptive array signal processor 100a-i of FIG. 3. The adaptive array signal processor 100a-i ~~of FIG. 5 is identical to that~~ 100-i of FIG. 2 except that in FIG. 5, the adaptive array weight calculator 112-i has been replaced with an adaptive array weight calculator 120-i. The operation of the adaptive array weight calculator 120-i is shown in FIG. 6. In FIG. 6, the weight calculator 120-i detects a response vector **Ui** by using the reference code included in the despread output $y_{i,1}$ through $y_{i,4}$ from the respective matched filters 111 in step 122. Then, the weight calculator 120-i inputs the inverse matrix Φ^{-1} in step 124, and calculates, in step 126, the weight vector **Wi'** according to the following equation:

$$\mathbf{Wi'} = \Phi^{-1} \cdot \mathbf{Ui}. \qquad (7)$$

Since the remaining portions are identical to corresponding portion of FIG. 2, the operation of the remaining portions are identical to that of the corresponding portion of FIG. 2.

As seen from the above description, the present embodiment calculates

only the common correlation matrix Φ and the inverse matrix Φ^{-1} thereof, whereas the prior art system calculates the N correlation matrices $\Phi 1$ through ΦN and the N inverse matrices Φ^{-1} thereof. Thus, the present embodiment enables a large reduction in the amount of calculation.

Also, it is noted that the weight vectors Wi' (i=1, 2,..., N) calculated in accordance with the first illustrative embodiment is not equal to the weight vectors Wi calculated in a prior art system. However, the difference between the vectors Wi' and Wi are generally very small. We discuss the properties of the weight vector in the following.

It is assumed that a reception signal of each user obtained from the M antennas is expressed by a reception signal vector:

$$\mathbf{Vi} = (V_{i,1}, V_{i,2}, \ldots, V_{i,M}),$$

where $V_{i,j}$ indicates the level of a reception signal of a user i which is obtained from an antenna j and which does not include the carrier component. Then, it is well known in the art that the correlation matrix Φ is given by:

$$\Phi = \sum_{i=1}^{N} V_i \bullet V_i^H, \tag{9}$$

where $\mathbf{A}^H$ is a transposed conjugate of the matrix $\mathbf{A}$.

On the other hand, in the prior art, the correlation matrices $\Phi 1$ through ΦN are calculated for the signals that have passed through the matched filters 111. For example, the correlation matrix Φi calculated for the signals of user 1 that have passed through the matched filters 111 is express as:

$$\Phi 1 = \sum_{i=1}^{N} |a_i|^2 V_i \bullet V_i^H, \tag{10}$$

where a_i indicates the correlation between a spreading code of user 1 and a spreading code of user i and is expressed as:

$$a_i = E\{c_1(t) \cdot c_i(t)\}, \tag{11}$$

where E{A} is an average of A during the same period of time as the averaging

period in the correlation matrix calculation. In the CDMA, though the correlation a_i ($i \geqq 2$) between the spreading code of user 1 and the spreading code of other user i slightly vary depending on user i, the correlations a_2 through a_N are substantially identical to each other. For example, in the W-CDMA the introduction of which is under examination in Japan, it is under consideration whether to use, as the spreading codes of the users, long codes the period of which is very long. If such codes are used, then the spreading code $c_i(t)$ of each user has a sufficient randomness, causing the time-averaging of E{ } to equalize the correlations of the users to each other.

If the correlations of the spreading codes between user 1 and other user i ($i \neq 1$) are perfectly identical to each other, then the weight vectors **Wi** and **Wi'** are expressed as follows:

$$\mathbf{Wi} = \left(\sum_{i=2}^{N} |a_i|^2 \mathbf{V}_i \bullet \mathbf{V}_i^H\right)^{-1}\mathbf{U}_i = |a_i|^2 \left(\sum_{i=2}^{N} \mathbf{V}_i \bullet \mathbf{V}_i^H\right)^{-1}\mathbf{U}_i \quad (12)$$

$$\mathbf{Wi'} = \left(\sum_{i=2}^{N} \mathbf{V}_i \bullet \mathbf{V}_i^H\right)^{-1}\mathbf{U}_i \quad (13)$$

It is noted that since a desired signal component (i = 1) has no influence on the value of the weight in the correlation matrix in the expression (12) and (13), the notation for i = 1 has been omitted. As seen from expression (12) and (13), the weight vectors **Wi** and **Wi'** are only different in the scalar and share an identical direction. In weight operation, the scalar of the weight is meaningless, what is important is one the direction of the weight. For this reason, the weight vectors **Wi** and **Wi'** can be considered to be equivalent to each other.

That is, if the spreading code correlations a_2 through a_N among N different users are perfectly identical to each other, then the weight vector **Wi'** is equivalent to **Wi**. Also, if the spreading code correlations a_2 through a_N vary depending on the user, then the weight vector **Wi'** does not match the weight

vector **Wi** but has a value close to **Wi.** Though we have made the above discussion in conjunction with a case of the desired signal being a signal from user 1, the above described properties are also true to the other users.

As described above, the weight vector for each user calculated in accordance with the present invention has a value vary close to that of prior art adaptive array antenna. Accordingly, the present invention can realize an adaptive array antenna system of a substantially optimal state with a reduced amount of calculations.

Also, if a long code the period of which is vary long is used for the spreading codes for the users, then calculating the correlation matrix in a stage preceding the matched filters as is done in the present invention makes the convergence of calculations fast as compared with calculating the correlation matrix for the signals that have been passed through the matched filters and reduces errors in calculation. That is, the output of each matched filter 111 includes mutual correlations with other users as interference components. If a long code is used, then the level of the mutual correlations changes depending on the symbol. For this reason, calculating the correlation matrices Φ **1** through Φ **N** by using the output signals of the matched filters 111 causes the convergence time in the correlation matrix calculation to become long. On the other hand, if the calculation of the correlation matrix is executed at a stage preceding the matched filters 111 in accordance with the present invention, then since no mutual correlation occurs, the level of the interference signals can be regarded as a constant during a process period, causing the correlation matrix Φ to converge fast and reducing errors.

Further, the correlation matrices calculated in a downstream path of the matched filters 111 includes a large magnitude of the desired signal component, which has no effect on the weight vector when the weight vector

has complete converged or has reached a stationary state but may cause an error in the weight vector if the weight vector has not yet converged. On the other hand, the correlation matrix Φ found in accordance with the invention includes a less magnitude of the desired signal component, which hardly causes an error in the weight vector.

It should be noted that calculating the correlation matrix Φ in an upstream path of the matched filters 111 enables the period of correlation matrix calculation to be set to any desired value such as the symbol period, the chip time (or the code period), etc.

To sum up, an antenna signal processing system 30, an adaptive array antenna portion 2 of a multi-user CDMA receiver according to the present invention not only reduces the amount of calculations in the weight vector calculation but also exhibits desirable output signal characteristics if a long code is used, and also enables the correlation matrix to be calculated in a desired period.

In this specific embodiment, the response vector Ui is calculated on the basis of the reference signals included in the outputs of the matched filters 111 in each adaptive array weight calculator 120-i. However, in a user data transmission period other than reference signal transmission period, the signals output from the matched filters 111 may be detected and thedetected signals may be used as the reference signals to obtain the response vector.

The adaptive array weight calculator 120-i may be so configured as to perform a signal processing by treating, as zero, some of the elements of the response vector if the values thereof are sufficiently small.

The same weight as that of the prior art Equal Gain Combining or Selection Combining may be used as the response vector.

As seen from above, the response vector Ui has not necessarily to be in

the form as described in the above-described illustrative embodiment.

A RAKE Receiver according to Embodiment I

FIG. 7 is a schematic block diagram showing an arrangement of a RAKE receiving portion 300-i which, when substituted for the adaptive array signal processor 100a-i in FIG. 3, enables the antenna signal processing system 30 to realize a RAKE reception. In FIG. 7, the RAKE receiving portion 300-i associated with user (or mobile station) i comprises M matched filters 111 each configured to match the spreading code of user i; a plurality of (P) adaptive array signal processors 100b-i-1 through 100b-i-P (P is the number of signals to be extracted which signals have propagated through different radio paths); and a signal combiner 302 for combining the output signals $z_{i,1}$ through $z_{i,P}$ from the P adaptive array signal processors 100b-i to provide a combined signal zi. The number of propagation path-different signal to be received, P, may be set to any suitable integer larger than one. In this specific example, P is set to three. The signals that have passed through the matched filters 111 are supplied to each of the three adaptive array signal processors 100b-i-1 through 100b-i-3. Each adaptive array signal processor 100b of FIG. 7 is identical to that 100a of FIG. 5 expect that the matched filters 111 have been removed, yet the outputs of the matched filters 111 are connected to the adaptive array weight calculator 120-i input terminals and to the input terminals of respective multipliers 113.

The adaptive array signal processors 100b are identical to each other in structure. In a RAKE receiver (not shown) or antenna signal processing system 30 incorporating this RAKE receiving portions 300, the inverse matrix Φ^{-1} of a common correlation matrix Φ is used for each RAKE receiving portion 300-i that uses delay taps and for each adaptive array signal processor 100b-i-p (p = 1, 2, 3 in this specific example). A response vector Ui,p is calculated for a corresponding delay tap in each adaptive array weight

calculator 120-i-p of each RAKE receiving portion 300-i.

According to the present invention, an antenna signal processing system 30 or an adaptive array antenna portion 2 incorporating the RAKE receiving portions 300 only requires the calculation of a common correlation matrix and a inverse matrix calculation. Considering that prior art RAKE receivers require $N \cdot P$ calculations of correlation matrices and $N \cdot P$ inverse matrix calculations, it is clear that an antenna signal processing system 30 or an adaptive array antenna portion 2 incorporating the RAKE receiving portions 300 enables a large reduction in the amount of calculations involved in the weight vector calculation.

Though we discussed a multi-user case in the above example, the invention is also applicable to a single user RAKE receiver.

It should be noted that using an above-mentioned long code for the spreading code enables an inventive RAKE receiver to have desirable output signal characteristics as described above.

Embodiment II

FIG. 8 is a schematic block diagram showing an arrangement of a multi-user CDMA receiver in accordance with a second illustrative embodiment of the invention. In FIG. 8, the multi-user CDMA receiver 3 is identical to that 2 of FIG. 3 except that the antennal signal processing system has been changed from 30 to 40. The antennal signal processing system 40 of FIG. 8 is identical to that 30 of FIG. 3 except that in FIG. 8:

the matrix calculator has been changed from 200 to 420;

a signal converter 440 has been inserted in the output signal (x1 through x4) path from the radio portions 10 on the downstream side of the input points of the matrix calculator 420;

the output of the matrix calculator 420 has been connected to the

signal converter 440; and

the adaptive array signal processors have been changed from 100a to 100c.

FIG. 9 is a flowchart showing an exemplary operation of the matrix calculator 420 of FIG. 8. In FIG. 9, the matrix calculator 420 first calculates the common correlation matrix Φ by using the radio portion 10 output signals x1 through x4 in the same manner as described in the first embodiment in step 422. In step 424, the matrix calculator 420 performs an eigen-analysis of the correlation matrix Φ to find eigenvalues $\{\lambda_j \mid j = 1, 2, \ldots, M\}$ and eigenvectors $\{\mathbf{e}_j \mid j = 1, 2, \ldots, M\}$. A numeral M is the number of antennas. Then, in step 426, the matrix calculator 420 calculates a conversion matrix Λ as follows:

$$\Lambda = \left[\frac{\mathbf{e}_1}{\sqrt{\lambda_1}} \quad \frac{\mathbf{e}_2}{\sqrt{\lambda_2}} \quad \cdots \quad \frac{\mathbf{e}_M}{\sqrt{\lambda_M}} \right]^T. \tag{14}$$

Using thus obtained conversion matrix Λ, the signal converter 440 converts the complex baseband signals x1 through xM output from the radio portions 10 as follows:

$$[x1' \quad x2' \quad \cdots \quad xM']^T = \Lambda^H [x1 \quad x2 \quad \cdots \quad xM]^T, \tag{15}$$

where [x1 x2 $\cdots$ xM] indicates the input complex baseband signals, [x1' x2' $\cdots$ xM'] indicates the converted signals, $[\mathbf{A}]^T$ indicates the transposed matrix of **A**. This conversion is conducted every sampling period of the baseband signal. The converted signals x1', x2', $\cdots$, xM' are supplied to each of the adaptive array signal processor 100c-1 through 100c-N associated with respective users 1 through N.

FIG. 10 is a schematic block diagram showing an arrangement of an adaptive array signal processor 100c-i of FIG. 8. The adaptive array signal processor 100c-i of FIG. 8 is identical to that 100a-i of FIG. 5 except that in FIG. 10, the adaptive array weight calculator 120-i has been replaced with a

response vector detector 130. For this reason, the description of the same elements is omitted.

The response vector detector 130 obtains a response vector **Ui** by using a reference signal inserted in each of the despread signals from the matched filters 111 and outputs the obtained response vector **Ui** as the weight vector **Wi**. The weight-multipliers 113 multiplies the respective despread signals by the response vector **Ui**. The weight-multiplied despread signals are combined by the combiner 114. In this way, an adaptive array signal processor 100c-i associated with user i detects its own signals with the matched filters 111 and performs a maximum-ratio combining of the detected signals.

We discuss some properties of a combined signal output zi obtained in accordance with the second illustrative embodiment of the invention in the following. It is first assumed that the reception signals for user i is expressed as a vector:

$$\mathbf{Vi} \cdot s(t) = [V_{i,1}, V_{i,2}, \cdots, V_{i,M},] \cdot s(t), \qquad (16)$$

where $[V_{i,1}, V_{i,2}, \cdots, V_{i,M},]$ is the levels of the reception signals that include no modulation signal, and s(t) is the modulation component of the reception signals. Then, the output of the signal converter 440 is given by $\Lambda^H \cdot \mathbf{Vi} \cdot s(t)$. Also, the response vector **Ui** obtained in the response vector detector 130 is expressed as:

$$\mathbf{Ui} = \beta \cdot \Lambda^H \cdot \mathbf{Vi}, \qquad (17)$$

where β is a constant.

Thus, the combined signal zi for user i is given by:

$$\begin{aligned} zi &= \mathbf{Ui}^H \cdot \Lambda^H \cdot \mathbf{Vi} \cdot s(t) \\ &= (\beta\, \Lambda^H \cdot \mathbf{Vi})^H (\Lambda^H \cdot \mathbf{Vi} \cdot s(t)) \\ &= \beta (\Lambda \cdot \Lambda^H \cdot \mathbf{Vi})^H \cdot \mathbf{Vi} \cdot s(t)) \end{aligned} \quad , \qquad (18)$$

where $\mathbf{A}^H$ is a transposed conjugate of **A**.

As seen from expression (18), the equivalent weight for user i is expressed as $\Lambda \cdot \Lambda^H \cdot \mathbf{Vi}$. It is well known in the art that the following relationship exists between the conversion matrix Λ and the correlation matrix Φ. That is,

$$\Lambda \cdot \Lambda^H = \Phi^{-1}. \tag{19}$$

Thus, the equivalent weight vector is expressed by $\Phi^{-1} \cdot \mathbf{Vi}$, which is the same as the weight vector **Wi** used in the first embodiment. In sum, the second embodiment of the invention differs in configuration from the first embodiment but provides the combined signal output as that of the first embodiment.

Since the signal converter 440 is shared by all of the users, the converter 440 is effective to any change in the number of the users.

It should be noted that the antenna signal processing system 40 is completely separated into a signal conversion portion (420 and 440) that uses a common correlation matrix and a signal combining portion 100a based on the maximum-ratio combining. In this sense, the second embodiment of the invention is very advantageous if a currently used maximum-ratio combining receiver is to be changed to an adaptive array antenna receiver. That is, a adaptive array antenna receiver can be realized by inserting the conversion matrix calculator 420 and the signal converter 440 in the upstream path of a conventional signal combiner.

Thus, the second embodiment of the invention can be realized by using a conventional receiver.

A RAKE Receiver according to Embodiment II

A RAKE Receiver according to the second embodiment of the invention can be realized by using the RAKE receiving portions 300 of FIG. 7 for the adaptive array signal processors 100c in FIG. 8.

According the second illustrative embodiment of the invention, a conventional RAKE receiving and maximum-ratio combining receiver can be changed to a adaptive array antenna receiver by adding the conversion matrix calculator 420 and the signal converter 440. A conversion matrix calculator 420 and a signal converter 440 are shared by all of the users and the delay taps, thereby enabling the adaptive array reception with a reduced amount of calculations.

However, as is well-known in the art, if the level of eigenvalues λj is close to that of noises, then the output of the signal converter 440 mostly contains noises but hardly includes signal components. What is needed is to reduce the amount of calculations with the noise level suppressed. This is achieved by the following modification of this embodiment.

Modification

According to this modification, if any eigenvalue(s) exist(s) that is (or are) lower in level than a predetermined value, then the signal(s) converted with the low-level eigenvalue(s) and corresponding eigenvector(s) is (or are) not used for the subsequent process. Specifically, if the level of eigenvalue λ_2 is as low as the noise level, then the conversion vector calculator 440 outputs a conversion vector without the element using the eigenvalue λ_2 as follows:

$$\Lambda' = \left[\frac{\mathbf{e}_1}{\sqrt{\lambda_1}} \quad \frac{\mathbf{e}_3}{\sqrt{\lambda_3}} \quad \cdots \quad \frac{\mathbf{e}_M}{\sqrt{\lambda_M}}\right]^T. \qquad (20)$$

In response to the conversion vector Λ', the signal converter 440 performs a signal conversion as follows:

$$[x1' \quad x3' \quad \cdots \quad xM']^T = \Lambda'^H[x1 \quad x2 \quad \cdots \quad xM]^T, \qquad (21)$$

Since the output signals of the signal converter 440 do not include the signal(s) associated with eigenvalue(s) that is (are) judged to be the low level eigenvalue: i.e., the signal associated with λ_2 in this specific example, the

number of signals to be processed by the adaptive array signal processors 100a is equal to or less than M. This contributes to the reduction of the processing load in the adaptive array signal processors 100a.

It should be noted that this weak signal excluding strategy can be used in an upstream path of the matched filters in any adaptive array antenna-based system. Specifically, a test is made to see if a level of a signal applied to each of the matched filters is as low as noises; if so, then it is preferable to prevent the signal(s) so determined from being used in a subsequent stage, e.g., by not passing the signal(s) to the matched filters.

Though the SMI (Sample Matrix Inversion) algorithm has been used in the above-described embodiment, the invention is applicable with the RLS (Recursive Least Squares) algorithm.

Embodiment III

FIG. 11 is a schematic block diagram showing an arrangement of an RLS algorithm-based adaptive array signal processor 500 that can be substituted for the adaptive array signal processor 100a in FIG. 3. In FIG. 11, the RLS algorithm-based adaptive array signal processor 500 is identical to the processor 100a of FIG. 5 except that the adaptive array weight calculator has been changed from 120-i to 520-i and the output of the signal combiner 114 has been fed back to the adaptive array weight calculator 520-i.

In order to facilitate the description and understanding, the signals supplied from the radio portions 10 to the matched filters 111 is expressed as x1(k), x2(k), ..., xM(k). M is the number of antennas (M = 4 in this specific example), and k is a serial number assigned to the incoming symbols. Signals x1(k) through x4(k) passing through the respective matched filters 111 yields, at the filter 111 outputs, signals y1(k) through y4(k), respectively, which is hereinafter denoted en bloc as **Y(k)**.

Then, the adaptive array weight calculator 520-i updates the current weight $\mathbf{W(m)}$ according to the following equation by using the despread signal vector $\mathbf{Y(k)}$, the inverse matrix Φ^{-1} from the correlation matrix calculator 200 and the fed-back combined signal zi(k).

$$\mathbf{W(k+1)} = \mathbf{W(k)} + \gamma\, \Phi^{-1} \cdot \mathbf{Y(k)} \cdot \mathbf{e}^{*}\mathbf{(k)}, \tag{22}$$

where $\mathbf{e(k)} = \mathbf{r(k)} - \mathbf{W(k)}^{H} \cdot \mathbf{Y(k)}$, (23)

where $\mathbf{r(k)}$ is a vector expression for the current reference signals inserted in the matched filter 111 outputs $\mathbf{Y(k)}$.

Though the third embodiment of the invention uses the RLS algorithm, this embodiment has the same advantages as the first embodiment has.

In the just-described specific example, the RLS algorithm or the adaptive array weight calculator 520-i has used the despread signals $\mathbf{Y(k)}$. However, the radio portion 10 output signals may be used for the weight calculation as in case of the second embodiment shown in FIG. 8. In this case, the value $\Phi^{-1} \cdot \mathbf{X(k)}$ can be used in common to the users, enabling a further reduction in the amount of calculations.

As described above, according to the present invention, an antenna signal processing system 30 or an adaptive array antenna portion 2 incorporating the RAKE receiving portions 300 only requires the calculation of a common correlation matrix and a inverse matrix calculation, enabling a large reduction in the amount of calculations involved in the weight vector calculation.

Using an long code for the spreading code enables an inventive RAKE receiver to have desirable output signal characteristics.

Calculating the correlation matrices in a upstream path of the matched filters causes the desired signal components of the correlation matrices to become low in level, shortening the conversion time in the weight

calculation.

Many widely different embodiments of the present invention may be constructed without departing from the spirit and scope of the present invention. It should be understood that the present invention is not limited to the specific embodiments described in the specification, except as defined in the appended claims.